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California GAMA Special Study: Interpretation of Isotopic Data in the Sonoma Valley, California

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GAMA: AMBIENT GROUNDWATER MONITORING & ASSESSMENT PROGRAM SPECIAL STUDY

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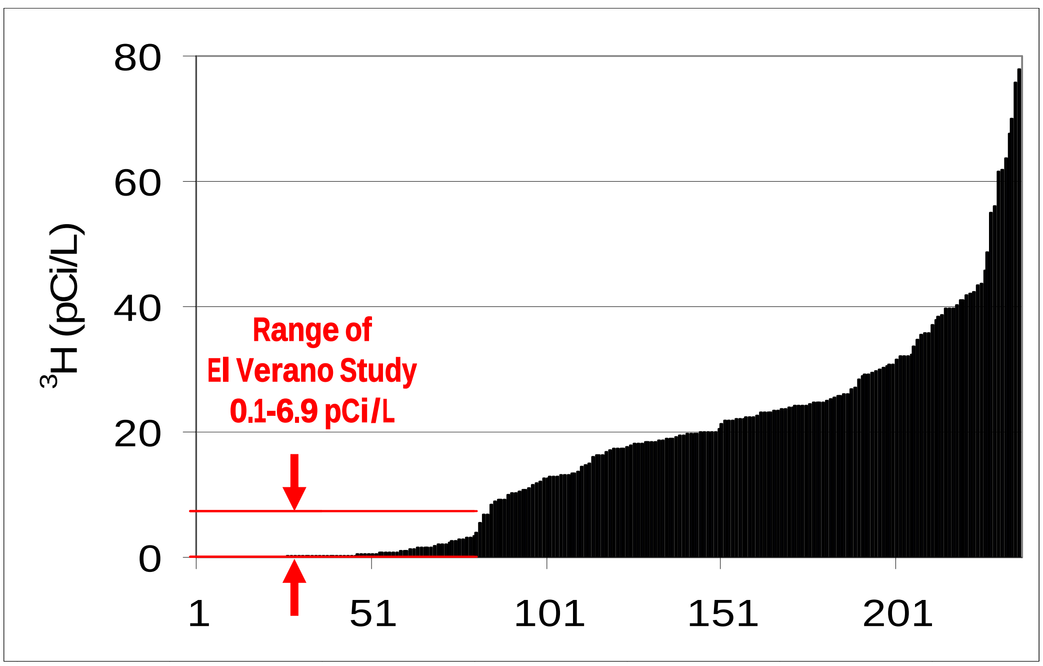

Final Report for GAMA Special Studies Task 9.3
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Prepared in cooperation with the California State Water Resource Control Board

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California GAMA Special Study: Interpretation of Isotopic Data in the Sonoma Valley, California

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Executive Summary

A shallow aquifer system near the city of El Verano in Sonoma Valley, California, supplies urban and rural water users. The source of recharge to this aquifer and its connection to Sonoma Creek are not well known, making its susceptibility and sustainability under different scenarios of land and water use difficult to assess. Under the State Water Resources Control Board Groundwater Ambient Monitoring and Assessment (GAMA) program, Lawrence Livermore National Laboratory carries out groundwater studies that focus on specific constituents of concern, or specific geographic areas where recharge and transport are not well determined. In this study, ten wells were sampled for tritium, helium isotopic composition, dissolved gas concentrations, concentrations of major anions and nitrate, and stable isotopes of water and of nitrate in order to examine sources of recharge, groundwater residence time, and water quality in the El Verano area.

Although sampled wells are relatively shallow (< 200 ft except deep monitoring wells and a deep drinking water well), the apparent tritium-helium (^3H-^3He) groundwater ages are all > 16 yrs. Furthermore, analysis of the measured tritium concentrations compared to the expected concentrations based on precipitation records indicates that tritiated groundwater is mixed with a large fraction (> 75% in all cases) of 'pre-modern' water (water that entered the aquifer system more than 50 years ago). Dispersion can account for apparently old ^3H-^3He ages and high fractions of pre-modern groundwater in shallow wells. Excess air results (dissolved gas in excess of equilibrium solubility entrained during recharge through the unsaturated zone) are not consistent with significant recharge from Sonoma Creek. Likewise, recharge temperatures, ^3H-^3He age, and fractions pre-modern suggest recharging waters migrate slowly through the unsaturated zone in the study area. Nitrate isotopic data indicate denitrification occurs between shallow oxidizing and deeper reducing zones. The sum of the evidence points to locally-derived (precipitation) recharge that is slow and aerially distributed, making susceptibility to contamination relatively low. However, the results also suggest that the area is susceptible to overdraft, given the long time period for groundwater replenishment.

Introduction

This study focuses on portions of the Carriger Creek fan and the City of El Verano, California, encompassing an area of several square kilometers (Figure 1). The area is within the Sonoma Creek watershed, in southeastern Sonoma County. Groundwater is a key component of the water supply, and is tapped for domestic use, public water supply, and irrigation of cultivated land. Sonoma County Water Agency and the U.S. Geological Survey are engaged in groundwater investigations that are aimed at providing information for enacting a groundwater management plan (Farrar et al., 2006; SCWA, 2007). According to Farrar et al. (2006), a portion of land covered by native vegetation has been converted to irrigated agricultural use (mainly vineyards) and urban/suburban development over the last 30 years. There has been a concurrent increase in groundwater extraction for irrigation, in the number of wells drilled, and in the depth of wells drilled. Farrar et al. (2006) present details of the geology and hydrology of the Sonoma Valley.

In the present study, isotopic and chemical constituents were analyzed to put constraints on the location, source, and timing of recharge to groundwater in the El Verano area. Specifically, the study employed tritium-helium age dating to constrain subsurface residence time, stable isotopes of the water molecule to identify source waters, and chemical constituents such as major anions and volatile organic compounds to examine changes in water quality during transport and to look for tracers of surface water/groundwater interaction. This GAMA Special Studies Project is part of a comprehensive assessment of groundwater in California. More information about GAMA is available at www.waterboards.ca.gov/gama/.

In January and February, 2008, Lawrence Livermore National Laboratory (LLNL) sampled 10 wells in the El Verano and Carriger Creek area of Sonoma Valley. Prior results from a municipal drinking water well in El Verano (2P2) that was sampled in 2004 as part of the statewide GAMA Priority Basin Study (Kulongoski et al., 2006) are also discussed. In addition, the two main creeks that drain the area were sampled during two periods of high runoff, and rainwater samples were collected over a one week period from a rain gauge at a private El Verano residence on Solano Avenue near Carriger Creek. All data are tabulated in Tables 1 through4.

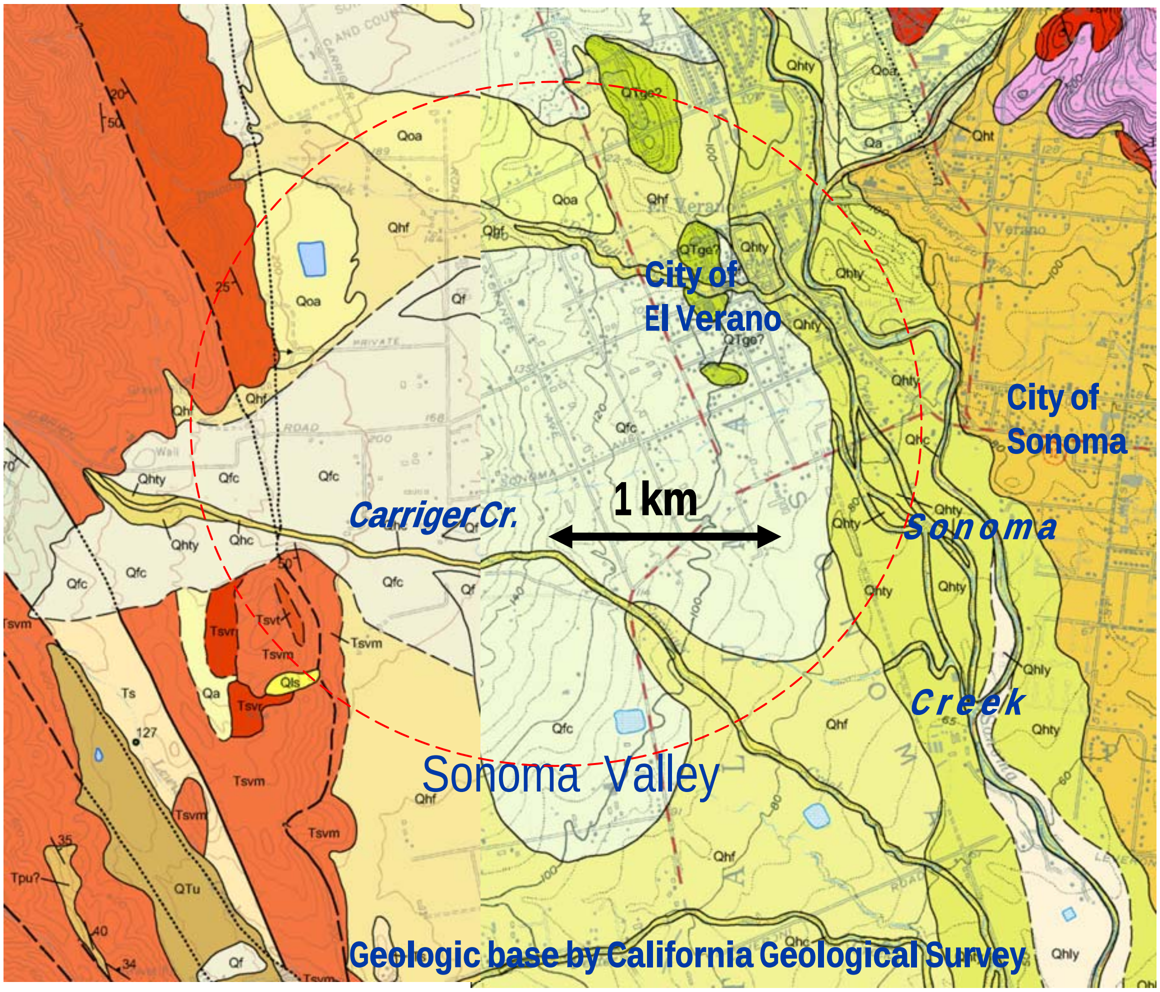

Figure 1. Study area for the ^3H-^3He data collected in the El Verano area of Sonoma Valley, California over geologic base compiled by California Geological Survey.

Isotopic Data in the Sonoma Valley, California

TRITIUM-HELIUM DATA

Figure 2 shows the locations of sampled wells, including screened interval (if known), ^3H-^3He apparent age, fraction pre-modern, and noble gas recharge temperature. (See Moran et al., 2005 for a description of the methodology used to calculate ^3H-^3He ages, fraction pre-modern, radiogenic ^4He, and noble gas recharge temperature.) ^3H-^3He apparent ages range from 16 to 43 years, fraction pre-modern ranges from 75 to 98%, and noble gas recharge temperatures range from 15.2 to 19.5 $^\circ$C. There are no clear trends to determine the source distribution of groundwater, except that the youngest ages (16 and 18 years) are found in the vicinity of Carriger Creek. However, considering that the fraction pre-modern fraction remains high 75-78%, these wells likely extract groundwater from more distant sources in addition to recharge along Carriger Creek. Data from the three wells in El Verano suggest a subtle age increase with depth with a consistently large fraction (94-98%) pre-modern groundwater.

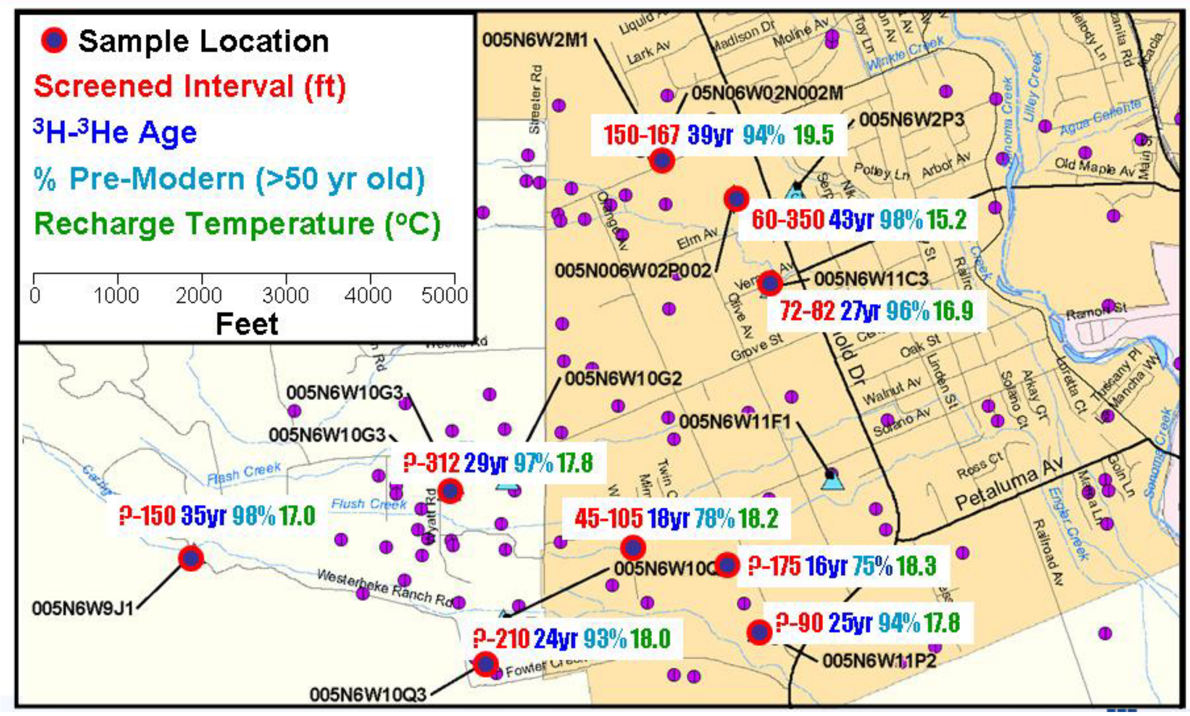

Figure 2. Map showing well locations and data for ^{3}H-^{3}He data collected, including screened interval (if known), ^{3}H-^{3}He apparent age (corrected for radiogenic ^{4}He contribution), fraction pre-modern, and noble gas recharge temperature.

Overall water quality is very good, with extremely low or non-detectable concentrations of volatile organic compounds (VOCs; Table 1), very low total organic carbon (TOC; Table 2) in streams (approximately 2 mg/L) and extremely low TOC in groundwater (0.2 mg/L). Total dissolved solids (TDS) in old, deep groundwaters are relatively low overall, only about 50% higher than average stream water values.

The most western well (9J1 in Tables 1 and 2; 005N6W9J1 in Figure 2) has a distinct chemical and isotopic signature suggesting that it is not part of the flow system represented by the other wells. The isotopic composition of water produced by this well is depleted in the heavier isotopes suggesting somewhat higher elevation recharge, has higher TDS, is a bicarbonate water, and is strongly reducing.

Figure 3 is a schematic drawing of a municipal well, a shallow monitoring well, two deeper monitoring wells, and a domestic water well in the El Verano area; open screened intervals are represented by shaded zones. Although the shallow monitoring well exhibits the youngest apparent groundwater age, its low tritium concentration indicates that the well also draws a large component of older, tritium-free water. An even older component, which contains measurable radiogenic ^{4}He, is found in the two deeper monitoring wells and in the drinking water well, but not in the shallow monitoring well. The municipal drinking water well (2P2) produces mixed aged water with the broadest age distribution;

it produces groundwater containing tritium, with a mean apparent ^{3}H-^{3}He age of 38 years, and a large component of older tritium-free water (98%), a fraction of which has a residence time of more than 200 years, based on the concentration of radiogenic ^{4}He.

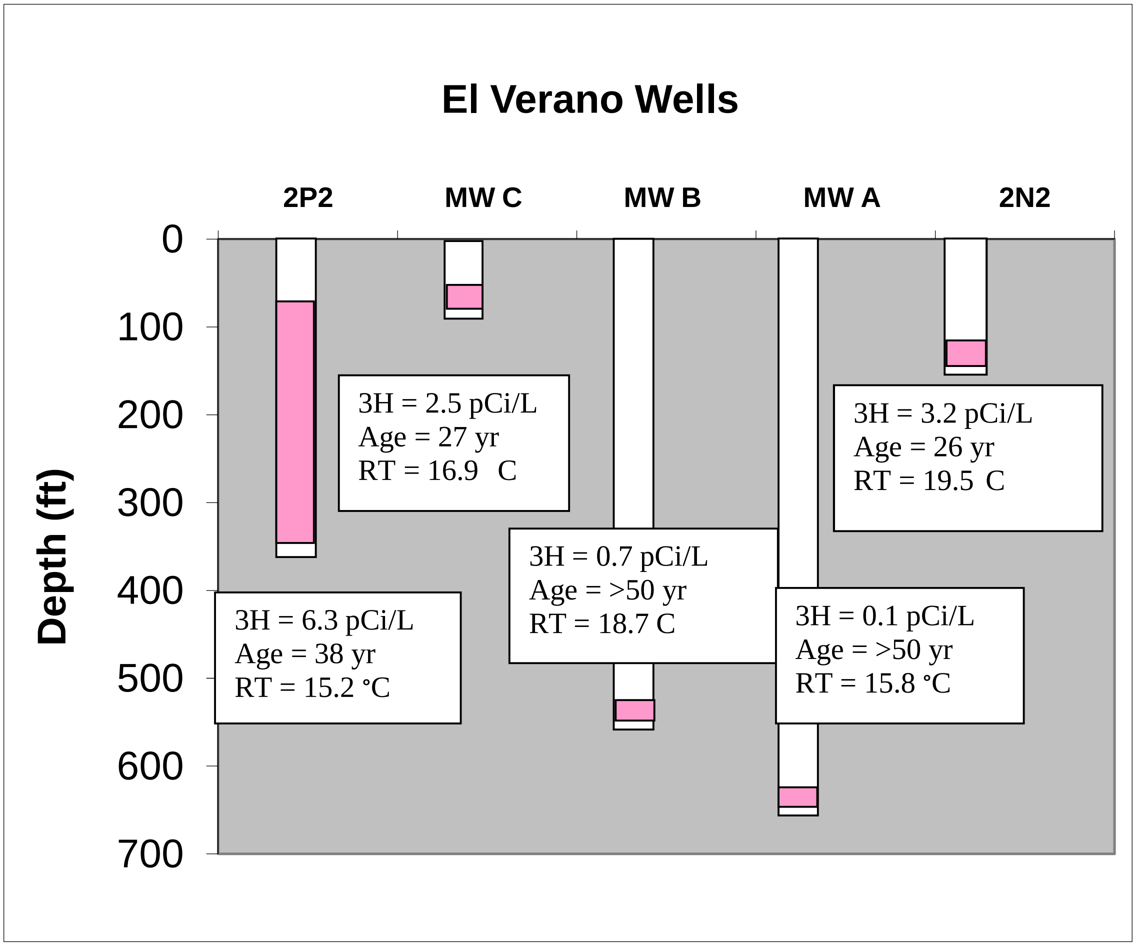

Figure 3. Schematic drawing of a municipal well (2P2), three monitoring wells (MW C, MW B, and MW A), and a domestic water well (2N2) in the El Verano area, with open screened intervals represented by shaded zones. Also shown are measured tritium concentrations, ^{3}H-^{3}He groundwater ages (uncorrected for radiogenic ^{4}He contribution), and calculated noble gas recharge temperature.

Figure 4 compares the range of tritium concentrations found in the El Verano study area compared to the composite distribution of tritium concentrations for wells sampled by GAMA program in California. Tritium concentrations in the El Verano study area fall in the lower third of the tritium distribution of GAMA samples in California. The relatively low tritium in the El Verano area is explained by the high fractions of pre-modern groundwater. Groundwater in shallow wells of the El Verano area has a relatively large pre-modern fraction compared to other wells sampled by the GAMA program in California.

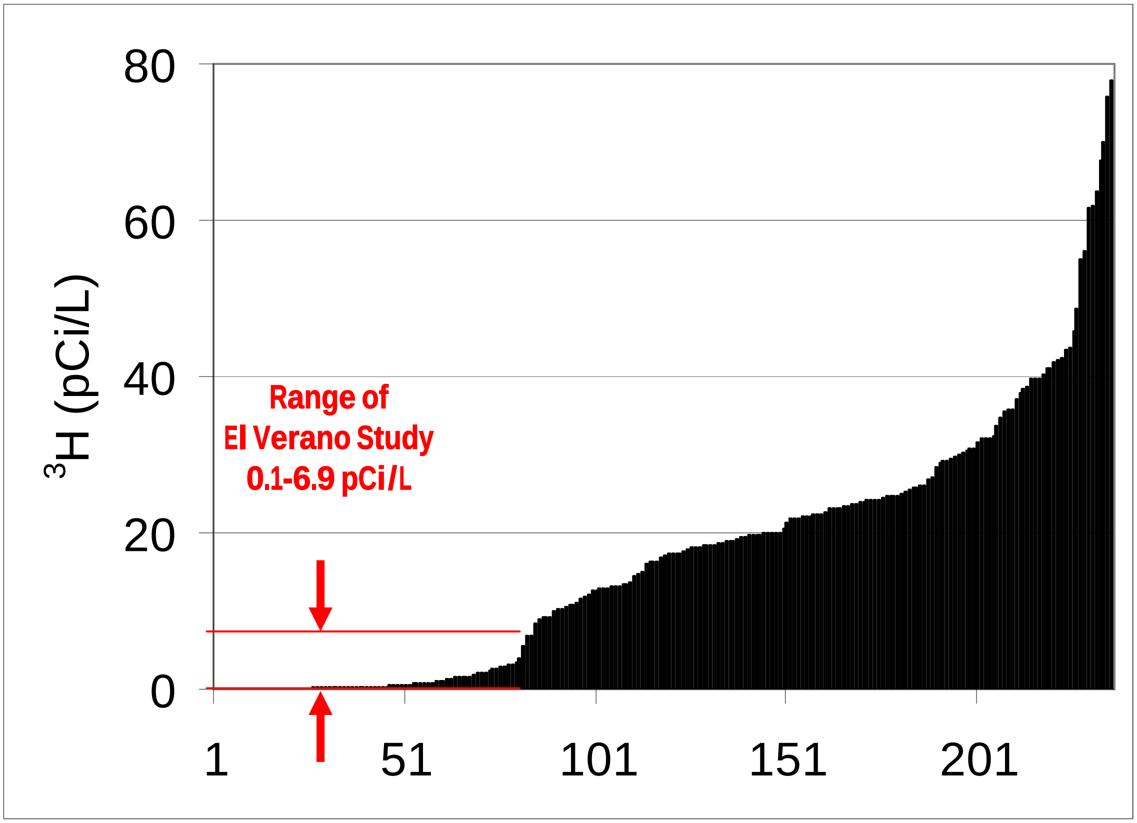

Figure 4. Comparison range of tritium concentrations found in the El Verano study area compared to composite distribution of tritium concentrations for wells sampled by GAMA program in California.

WATER ISOTOPES

Figure 5 shows results of the analysis of stable isotopes of the water molecule ($^2H/^1H$ and $^{18}O/^{16}O$) in wells, creek water, and precipitation. Precipitation samples show by far the largest range, reflecting short term variations in the direction of storms and their source of moisture. Two of the precipitation samples fall on the Global Meteoric Water Line (GMWL) and another three fall on a local meteoric water line, which is above and parallel to the GMWL. These are common observations for small sample sets of stable isotopes in precipitation in any setting. Surface water samples from Carriger Creek and Sonoma Creek fall in a relatively narrow range in the middle of the range in precipitation and within the range observed for groundwater samples. Surface water and groundwater stable isotope ranges suggest that the main source of overland flow and recharge to aquifers is local precipitation. There is no evidence for a significant component of water from higher elevation, nor is there evidence for significant evaporation before recharge.

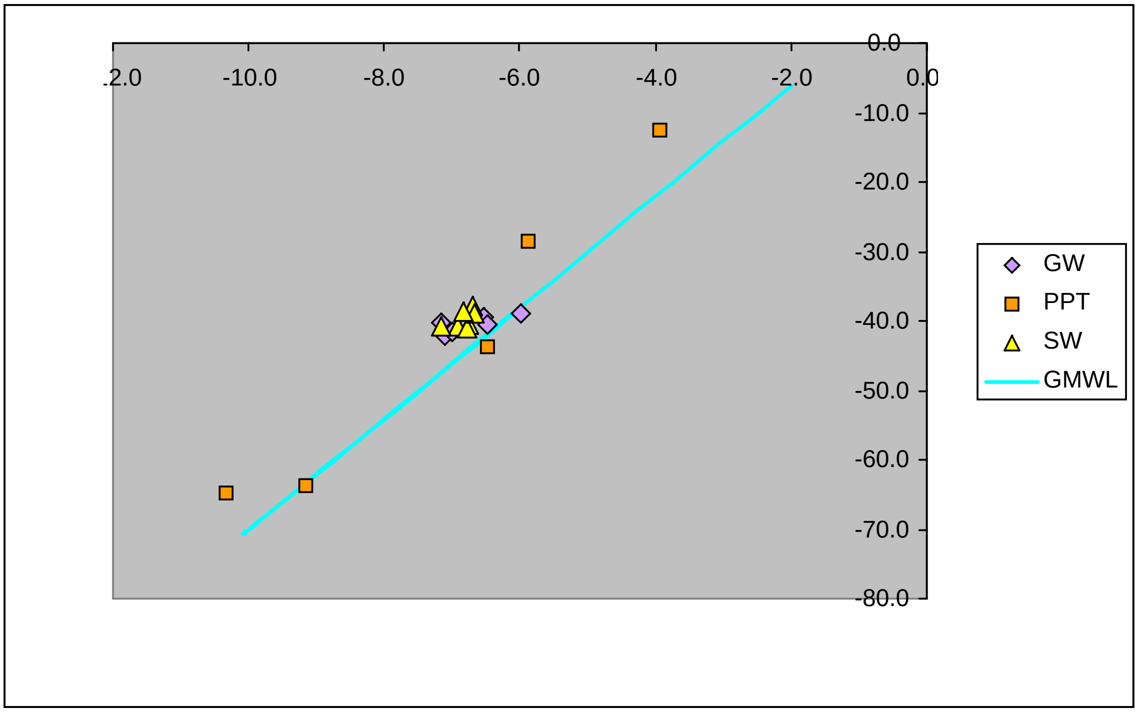

Figure 5. Stable isotopes of the water molecule (deuterium/protium and oxygen 18/16) in wells, creek water, and precipitation.

Groundwater Recharge Temperatures

Noble gas-derived groundwater recharge temperatures provide useful constraints on recharge and transport because recharge temperatures can indicate the source or location of recharge. Figure 6 compares groundwater recharge temperatures calculated from the concentrations of dissolved noble gases to wellbore temperature profiles (top) and the temperatures of discharged well water (bottom) for wells 11C3, 11C4, and 11C5 (monitor wells MW-C, B, and A in Figures 1 and 2) and other wells outside the study area.

For most samples, the calculated noble-gas recharge temperature is higher than the measured discharge temperature (Figure 6, bottom). Calculated recharge temperatures are also somewhat warmer than the mean annual air temperature for the region (Figure 6 bottom, orange oval), and are significantly warmer than stream water temperatures observed during the sampling period (Figure 5 bottom, blue oval). One explanation for these observations is that recharge is more likely during warmer Fall and Spring rain and flooding events, and less likely during cooler Winter events when antecedent water impedes infiltration and recharge. Alternatively, subsurface temperatures in the unsaturated zone where noble gases equilibrate with soil gas are warmer than mean annual temperature due to elevated geothermal gradients. Notably, the calculated noble gas recharge temperatures (Figure 6 bottom) largely align with the projection of wellbore temperatures toward the water table (the shallowest temperature measurements in Figure 6 top).

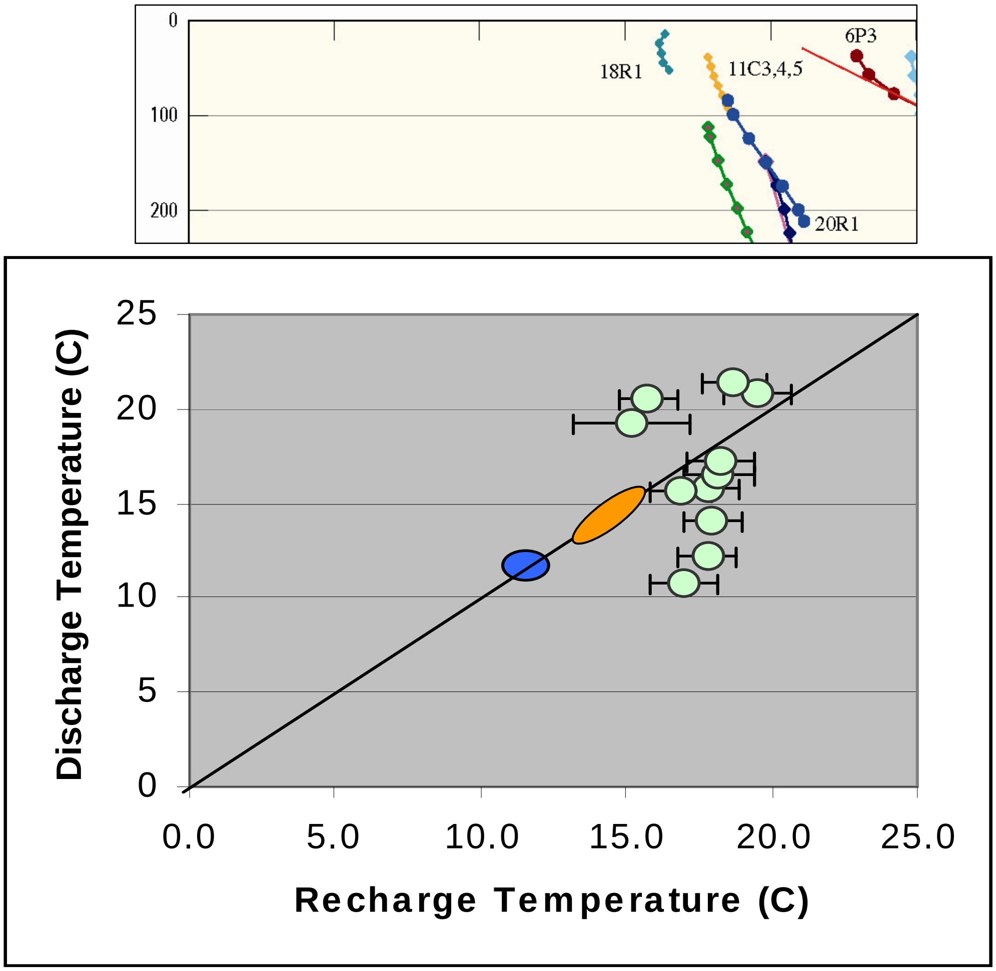

Figure 6. Top: Wellbore temperature profiles (Farrar et al., 2006) in wells 11C3, 11C4, and 11C5 and other wells outside study area. Bottom: Produced water temperature versus noble gas-derived recharge temperature for wells sampled in this study. Mean annual air temperature (as determined using NOAA/GISS data from the Healdsburg, Santa Rosa, and Napa stations) is shown by the orange oval. Stream water temperatures during the sampling period (January-February 2008) are shown by a blue oval. Note that the wellbore temperature data (top) are scaled on the x-axis to the temperature scale for the recharge temperature (bottom).

Except for the 2P2 production well and the deepest monitoring well (which have slightly lower recharge temperatures), the noble gas recharge temperatures fall in a very narrow range, suggesting that water infiltrates slowly enough to equilibrate with the unsaturated zone temperature near the water table. The narrow range of recharge temperatures (Figure 5, bottom) is similar to measured temperatures near the top of the saturated zone in wells 11C3, 11C4, and 11C5 (Figure 5, top). The noble gas recharge temperatures combined with measured temperatures in wells suggest groundwater recharge in the Carriger Creek and El Verano areas migrates through the unsaturated zone. Additionally, moderately high concentrations of ‘excess air’ (dissolved gas in excess of equilibrium solubility entrained during recharge through the unsaturated zone; Table 4) measured in these wells argue against stream recharge as the dominant recharge mechanism. The fact that the USGS study (Farrar et al., 2006) characterizes Sonoma Creek as a gaining stream in the El Verano area further supports groundwater recharge by percolation on the Carriger Creek Fan and not from Sonoma Creek.

The two wells exhibiting depressed recharge temperatures are characterized by relatively old ages and high concentrations of radiogenic ^{4}He. The lower recharge temperatures may therefore be evidence for a component of very old groundwater, recharged during a cooler climate.

NITROGEN AND OXYGEN ISOTOPES

Nitrate isotopic composition was determined in five wells (Figure 7). Four of the sample nitrate isotopic compositions fall in a narrow range for nitrate-δ^{15}N and three are grouped in a narrow range for both nitrate-δ^{15}N and nitrate-δ^{18}O. The δ^{15}N value of about 12‰ is in the range expected for animal waste or soil nitrate. The concentrations of nitrate are low but somewhat higher than expected for natural, background levels (except for one private well which had a concentration of 31 mg/L as nitrate, still well below the MCL of 45 mg/L).

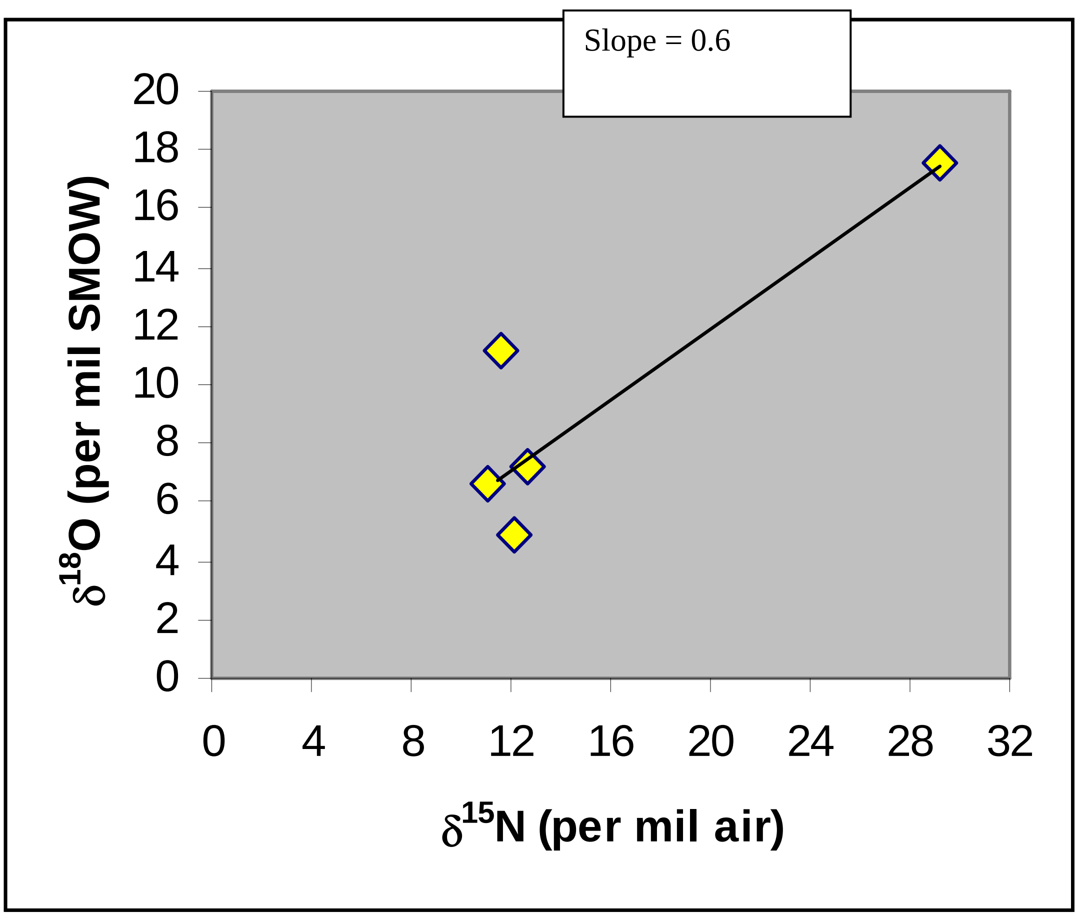

Figure 7. Results of analysis of five samples for nitrogen and oxygen isotopes of nitrate.

The most interesting finding regarding nitrate comes from the nested monitoring wells (MW A, B, and C in Figures 2 and 3). The shallow well, with 13 mg/L nitrate, is in an oxidizing regime, with a dissolved oxygen (DO) concentration of 3.4 mg/L and an oxidation/reduction potential reading of 121 mV, while the deeper well has 0.4 mg/L nitrate, a DO concentrations of 0.5 mg/L and an ORP of 51 mV, indicating transition to a reducing environment. A trend line on Figure 7 connects the isotopic composition of the shallow well to the heavier $\delta^{15}N$ and $\delta^{18}O$ values observed in the deeper well. The slope of the line is characteristic of denitrification, whereby the oxygen isotope ratio changes by approximately one half that of the nitrogen isotope ratio.

Conclusions

Interpretation of isotopic data in groundwater from the area around El Verano, California points to dispersed recharge of locally-derived water that reaches the capture zone of domestic supply wells after two or more decades. Dispersion can account for apparently old ^3H-^3He ages and high fractions of pre-modern groundwater in shallow wells (see Carle et al., 2010). Deep monitoring wells and a high capacity drinking water well draw even older water, containing little or no tritium, having entered the aquifer more than five decades ago. Recharge temperatures, ^3H-^3He age, and fractions “pre-modern” suggest recharging waters migrate through an unsaturated zone in the Carriger Creek, El Verano area. The interpretations of derived parameters from dissolved gas constituents rule out significant recharge from Sonoma Creek. Nitrogen and oxygen isotope data indicate denitrification occurs between shallow oxidizing and deeper reducing zones. Better interpretation of the ^3H-^3He data with respect recharge sources and processes can be achieved through construction of a two-dimensional groundwater flow model on the axis of Carriger Creek fan through El Verano to Sonoma Creek and more sampling points.

Acknowledgements: Jay Jasperse (Sonoma County Water Agency) first suggested an investigation of the Carriger Creek Fan/El Verano area as suitable to achieving the goals of the Special Studies task. Ed Nelson, a resident of El Verano, arranged permission to sample private domestic wells in the community, without which the study could not have been completed.

Presentations (Attached)

Carle, S. F., Moran, J. E., and Esser, B. K., 2008. Deep groundwater signatures in a shallow aquifer system, Sonoma Valley, California *Geological Society of America Annual Meeting (5 October 2008, Houston TX)*. LLNL-ABS-404457, LLNL-PRES-407652.

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Kulongoski, J. T., Belitz, K., and Dawson, B. J., 2006. Ground-Water Quality Data in the North San Francisco Bay Hydrologic Provinces, California, 2004: Results from the California Ground-Water Ambient Monitoring and Assessment (GAMA) Program. U.S. Geological Survey Data Series Report 167.

SCWA, 2007. Sonoma Valley Groundwater Management Plan. Sonoma County Water Agency.

Table 1. Field data for groundwater and surface water samples

LLNL ID	Local ID	Screened interval (ft bgs)	Sample Collection	Field Conductivity (µS/cm)	Field DO (mg/L)	Field ORP (mV)	Field pH	Field Temperature (°C)
	Private Domestic Wells							
106241	11P2	?-90	02/22/2008	353	6.2	130	7.07	15.9
106197	10Q4	45-105	01/25/2008	403	5.5	175	6.60	16.5
106238	2N2	150-167	02/22/2008	343	4.1	236	6.97	20.8
106239	9J1	?-150	02/22/2008	469	0.6	-126	7.27	10.8
106240	HW	?-175	02/22/2008	367	5.1	187	6.69	17.2
106196	10Q3	?-210	01/25/2008	359	5.1	147	6.62	14.0
106198	10G3	?-312	01/25/2008	320	7.2	165	7.31	12.2
	Public Supply Well							
***	2P2	60-350	10/19/2004	345	3.5		6.80	19.3
	Monitor Wells							
106195	11C3 (MW C)	72-82	01/25/2008	350	3.4	121	7.53	15.6
106193	11C4 (MW B)	542-552	01/25/2008	403	0.5	51	7.45	21.4
106194	11C5 (MW A)	654-664	01/25/2008	400	0.9	66	7.43	20.6
	Surface Water							
106159	Carriger Creek @ White Alder Road		01/06/2008					
106242	Carriger Creek @ Arnold Drive		02/22/2008	221	17.3	242	7.50	11.9
106156	Carriger Creek @ Arnold Drive		01/06/2008					
106243	Sonoma Creek @ Ig Vella Bridge		02/22/2008	265	16.8	268	7.57	11.1
106158	Sonoma Creek @ Ig Vella Bridge		01/06/2008					
106157	Sonoma Creek @ Agua Caliente Drive		01/06/2008					
106244	Dandahl Creek		02/22/2008	327	19.4	281	8.04	11.6

***LLNL data from GAMA Priority Basin Project (Kulongoski, 2006)

Table 2. Inorganic and organic chemical data for groundwater and surface water samples

LLNL ID	Local ID	Br (mg/L)	Cl (mg/L)	NO3 (mg/L)	NO2 (mg/L)	PO4 (mg/L)	SO4 (mg/L)	Chloroform (ng/L)	MTBE (ng/L)	Benzene (ng/L)	Carbon Disulfide (ng/L)
	Private Domestic Wells										**ng/L**
106241	11P2							7.7			
106197	10Q4	< 0.4	17.4	31.0	< 0.4	< 0.6	10.2	14.4			6.8
106238	2N2										
106239	9J1										7.0
106240	HW										38.8
106196	10Q3	< 0.4	16.4	4.1	< 0.4	< 0.6	8.5	68.4			
106198	10G3	< 0.4	10.7	9.7	< 0.4	< 0.6	12.5	6.0			
	Public Supply Well										
***	2P2										
	Monitor Wells										
106195	11C3 (MW C)	< 0.4	24.7	13.9	< 0.4	< 0.6	14.8	14.6			
106193	11C4 (MW B)	< 0.4	12.9	0.4	< 0.4	< 0.6	10.5				
106194	11C5 (MW A)	< 0.4	11.6	0.2	< 0.4	< 0.6	9.0				
	Surface Water										
106159	Carriger Creek @ White Alder Road										
106242	Carriger Creek @ Arnold Drive										
106156	Carriger Creek @ Arnold Drive							5.1			
106243	Sonoma Creek @ Ig Vella Bridge							10.9	5.2	6.4	
106158	Sonoma Creek @ Ig Vella Bridge							10.9	5.2	6.6	
106157	Sonoma Creek @ Agua Caliente Drive							12.5	6.7	7.1	
106244	Dandahl Creek							8.6			

***LLNL data from GAMA Priority Basin Project (Kulongoski, 2006)

Table 3. Stable isotope and DIC/TOC data for groundwater and surface water samples

LLNL ID	Local ID	Screened interval (ft bgs)	$\delta^{15}N$ NO_3 (‰, SMOW)	$\delta^{18}O$ NO_3 (‰, SMOW)	$\delta^{18}O$ H_2O (‰, SMOW)	δD H_2O (‰, SMOW)	$\delta^{13}C$ DIC (‰, PDB)	$\delta^{13}C$ TOC (‰, PDB)	DIC (mg/L)	TOC (mg/L)
	Private Domestic Wells									
106241	11P2	?-90		12.2	-6.5	-40	-18.0		28.2	0.20
106197	10Q4	45-105	12.2	4.9	-6.9	-41	-17.3		37.4	0.20
106238	2N2	150-167			-6.5	-40	-17.1		31.5	0.20
106239	9J1	?-150			-7.1	-42	-16.6		50.9	0.20
106240	HW	?-175			-7.2	-40	-18.0	-21.7	38.7	0.20
106196	10Q3	?-210	11.7	11.2	-7.0	-41	-16.6	-23.8	38.0	0.65
106198	10G3	?-312	12.6	7.2	-6.5	-41	-17.6		30.7	0.20
	Public Supply Well									
***	2P2	60-350			-6.0	-39	-20.0		30.4	
	Monitor Wells									
106195	11C3 (MW C)	72-82	11.0	6.6	-6.3	-42	-18.5		28.1	0.20
106193	11C4 (MW B)	542-552	29.2	17.5	-6.7	-45	-18.7		43.0	0.20
106194	11C5 (MW A)	654-664			-6.7	-46	-18.9		43.7	0.20
	Surface Water									
106159	Carriger Creek @ White Alder Road				-6.8	-39				
106242	Carriger Creek @ Arnold Drive				-6.9	-41	-9.5	-26.4	20.0	2.15
106156	Carriger Creek @ Arnold Drive				-7.2	-41				
106243	Sonoma Creek @ Ig Vella Bridge				-6.8	-41	-13.2	-26.2	23.6	2.10
106158	Sonoma Creek @ Ig Vella Bridge				-6.7	-39				
106157	Sonoma Creek @ Agua Caliente Drive				-6.8	-41				
106244	Dandahl Creek				-6.7	-38				
	Precipitation	**Rainfall (inches)**								
106232	El Verano, 01/25-26/08	4.5			-10.3	-65				
106233	El Verano, 01/26-27/08	0.7			-9.2	-64				
106234	El Verano, 01/27-28/08	0.3			-6.5	-44				
106235	El Verano, 1/29-30/08	0.4			-3.9	-13				
106236	El Verano, 01/31-02/01/08	1.9			-5.9	-28				

***LLNL data from GAMA Priority Basin Project (Kulongoski, 2006)

Table 4. Tritium and noble gas data and derived parameters for groundwater samples

LLNL ID	Local ID	Screened interval (ft bgs)	Tritium (pCi/L)			Excess air (cm3 STP/g)	3H-3He age (yr)			Corrected 3H-3He age (yr)			Fraction premodern water	Recharge temperature (°C)			Radiogenic 4He age (yr)
	Private Domestic Wells																
106241	11P2	?-90	3.12	±	0.21	0.0029	24.8	±	5.2	31.1	±	2.4	94%	17.8	±	1.1	0.0.E+00
106197	10Q4	45-105	6.70	±	0.41	0.0047	18.2	±	4.2	NC			78%	18.2	±	1.2	1.5.E+05
106238	2N2	150-167	3.17	±	0.20	0.0035	25.9	±	5.3	38.7	±	3.9	94%	19.5	±	1.2	9.9.E+01
106239	9J1	?-150	1.88	±	0.15	0.0045	34.9	±	0.0	NC			98%	17.0	±	1.2	4.6.E+02
106240	HW	?-175	6.95	±	0.36	0.0039	16.3	±	4.2	23.1	±	2.0	75%	18.3	±	1.2	0.0.E+00
106196	10Q3	?-210	2.96	±	0.27	0.0004	23.9	±	5.0	NC			93%	18.0	±	1.0	2.1.E+04
106198	10G3	?-312	2.25	±	0.20	0.0010	28.6	±	5.4	NC			97%	17.8	±	1.0	7.2.E+04
	Public Supply Well																
***	2P2	60-350	6.28	±	0.33	NC	38.0	±	1.0	43.0	±	1.0	98%	15.2	±	2.0	2.1.E+02
	Monitor Wells																
106195	11C3 (MW C)	72-82	2.51	±	0.23	0.0026	26.7	±	5.7	26.7	±	1.8	96%	16.9	±	1.1	0.0.E+00
106193	11C4 (MW B)	542-552	0.74	±	0.16	0.0027	>50			>50			100%	18.7	±	1.1	1.6.E+04
106194	11C5 (MW A)	654-664	0.07	±	0.17	0.0024	>50			>50			100%	15.8	±	1.0	4.0.E+03

***LLNL data from GAMA Priority Basin Project (Kulongoski, 2006)
NC = not calculated

LLNL-ABS-404457
LLNL-PRES-407652

Deep Groundwater Signatures in a Shallow Aquifer System, Sonoma Valley, California

CARLE, Steven F, MORAN, Jean E, and ESSER, Bradley K

June 3, 2008

Geological Society of America Annual Meeting
Houston, Texas
October 5, 2008

Auspices Statement

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

LLNL-ABS-404457

Deep Groundwater Signatures in a Shallow Aquifer System, Sonoma Valley, California

CARLE, Steven F.[1], MORAN, Jean E.[2], and ESSER, Brad K.[2], (1) National Security Engineering Division, Lawrence Livermore National Laboratory, L-231, POB 808, Livermore, CA 94551, carle1@llnl.gov, (2) Chemical Sciences Division, Lawrence Livermore National Laboratory, L-231, POB 808, Livermore, CA 94551

A shallow aquifer system near the city of El Verano in Sonoma Valley, California, supplies urban and rural water users. In this study, nine wells ranging in depth from 82 to 674 feet were sampled for tritium and 3-helium to estimate groundwater age. Seven wells 90 to 312 feet deep yielded a non-zero fraction of modern (< 50 year old) groundwater. However, the modern fraction ranged from only 2 to 7% for five of these seven wells, with apparent ages of 24-29 years. For two relatively shallow wells (~100 feet deep) closer to a stream, modern fractions increased to 22-25%, and apparent age decreased to 16-18 years, indicating closer proximity to a recharge sources.

Stable isotopes of the water molecule in local precipitation, streams, and groundwater fall within a narrow range, indicating locally derived water as the source of recharge. In deeper wells, colder noble gas recharge temperatures suggest a component of recharge dating back thousands of years. Radiogenic 4-helium concentrations up to 4.0e-6 cc(STP)/g indicate contribution from deep groundwater sources in both deep and shallow wells.

These groundwater age and isotopic data indicate groundwater supplies in the El Verano area mostly originate from pre-development recharge and deep sources. Even the shallowest wells are remotely connected to local recharge processes. Water level data show declining trends with depth. Simulation of gas-liquid phase flow and transport of water, air, tritium, and 3-helium components is used to reconcile age data with groundwater level trends. Hydrostratigraphy of thin aquifers and thick aquitards having depth-decreasing permeability yields simulation results consistent with the data. In terms of groundwater age and isotopic signature, this shallow aquifer system behaves like a relatively deep basin.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. DE-AC52-07NA27344.

LLNL-PRES-407652

Lawrence Livermore National Laboratory

Deep Groundwater Signatures in a Shallow Aquifer System, Sonoma Valley, California

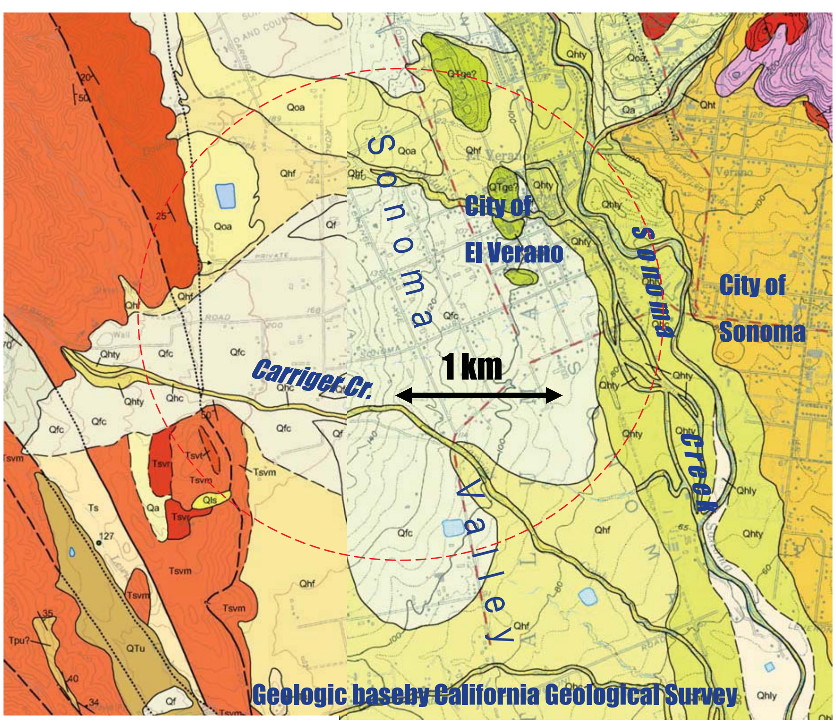
Steven F. Carle, Jean E. Moran, and Brad K. Esser

Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, CA 94551

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

LLNL-PRES-*******

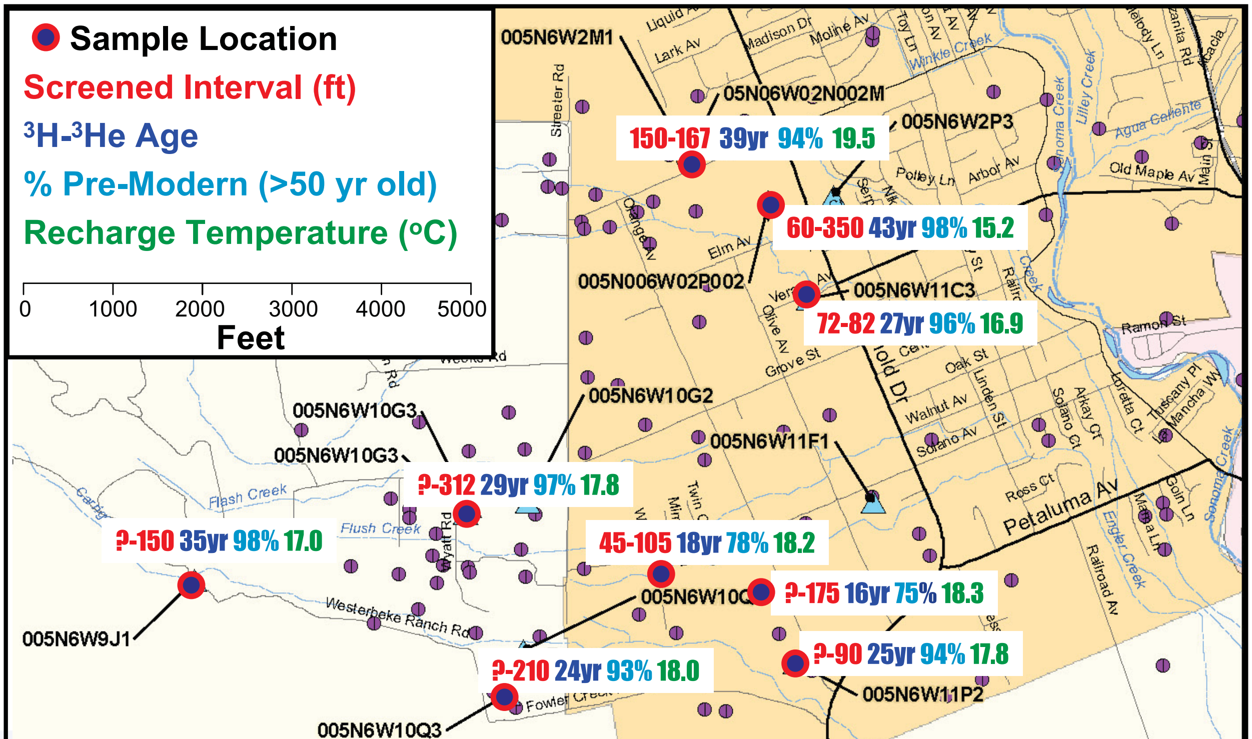
El Verano Groundwater Age Study Area Sonoma Valley, California



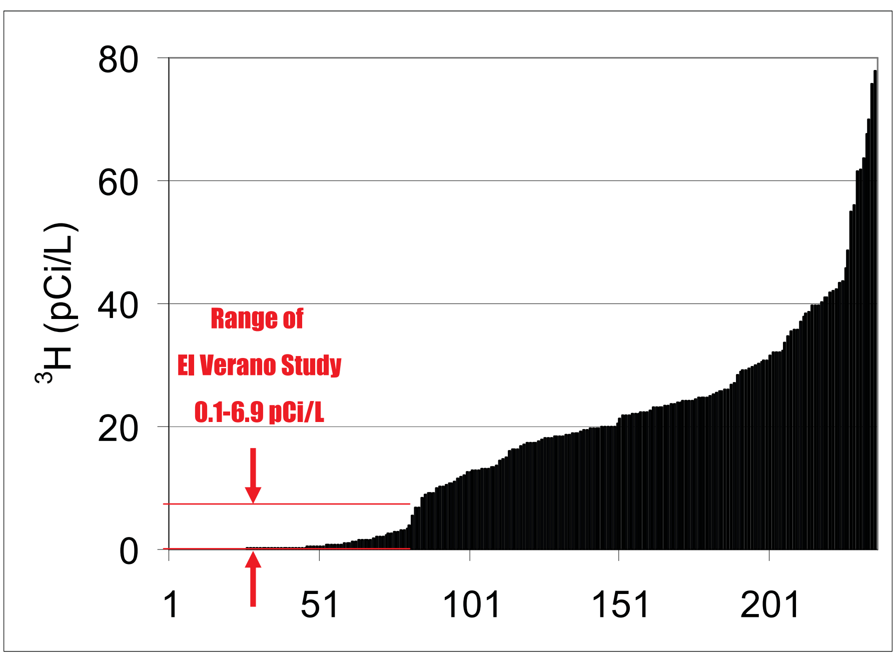
Outline:

- ^3H-^3He data
- Interpretation
- Reactive Transport Modeling Approach
- Future Work

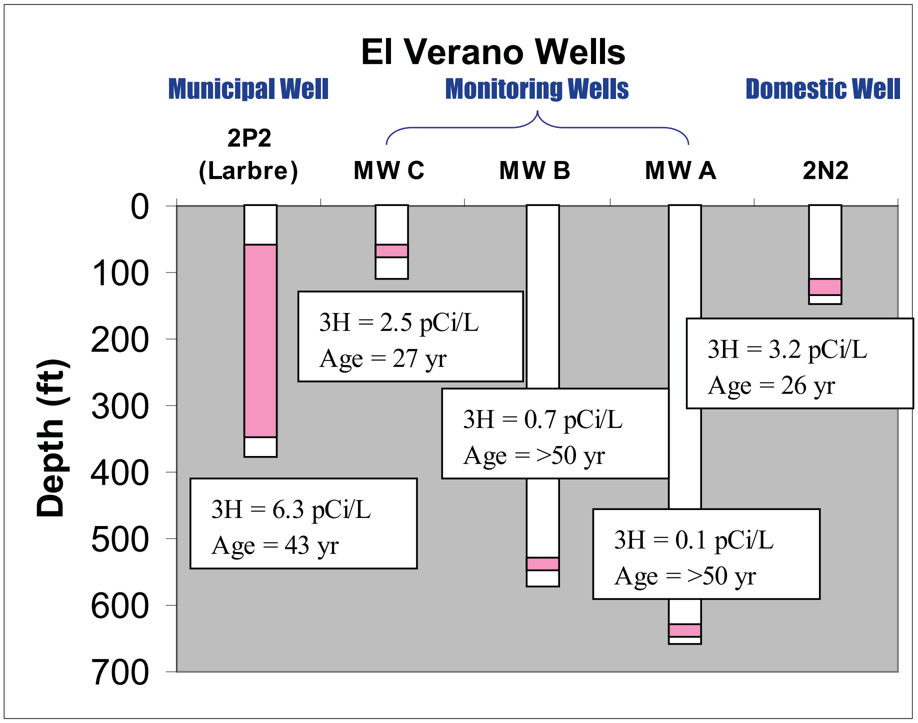
El Verano Area Groundwater Age Study Data



GAMA (Groundwater Monitoring and Assessment) distribution of ^3H in Samples from California



Shallow wells have relatively deep ^3H-^3He signatures. Deep wells have all "pre-modern" (>50 yr) groundwater.



El Verano Area Groundwater Age Study
Overall Results:

- Well depths 82-350 (mostly < 200 ft)
- Recharge Temperatures 15.2-19.5 ^{O}C
- ^{3}H-He ages 16-43 years
- % Pre-Modern 75-98%
- What causes these deep groundwater signatures in relatively shallow wells?

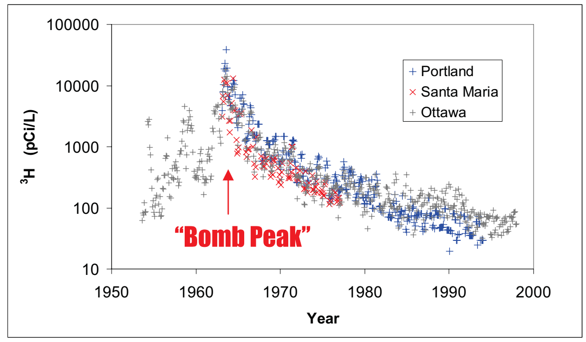
Tritium Helium-3 (^3H-^3He) Groundwater Age Estimation

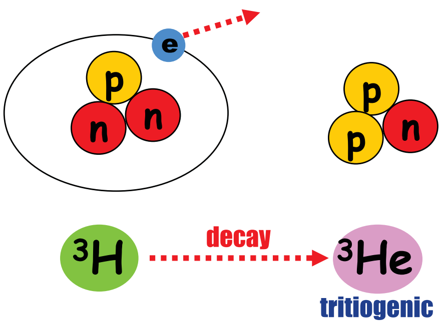
+

cosmogenic ^3H

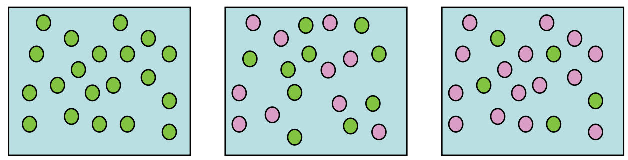
precipitation

^3H in Surface Water





^3H and ^3He in Groundwater (saturated zone)

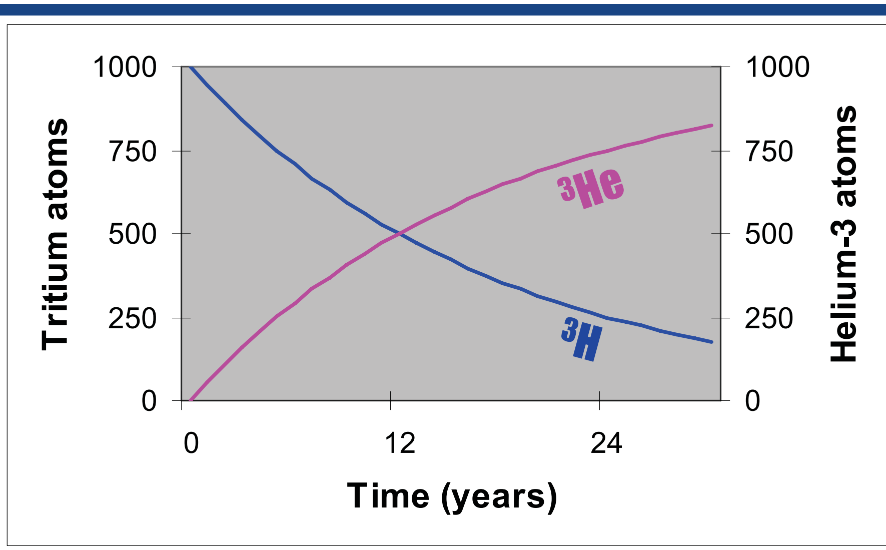


0 years

12.3 years (1/2 life)

24.6 years

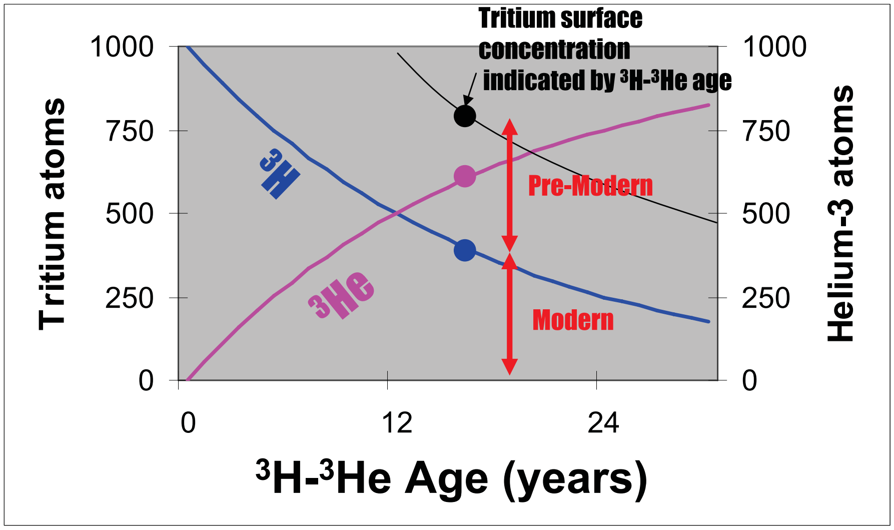
$$^3H\text{-}^3He \text{ Age (years)} = 17.8 \times \ln(1 + {^3He} / {^3H})$$



Two problems:

1. **^3H-^3He is a first-order decay process.**
2. **^3H source is not constant because of bomb peak.**

% “Pre-Modern” = 100% (1 – $^3H_{meas}/^3H_{source}$)

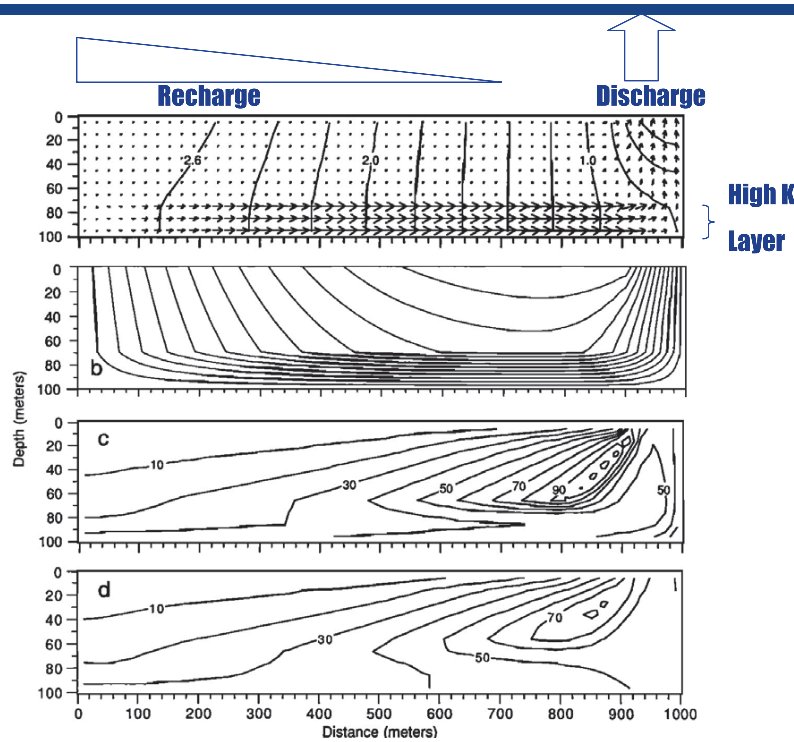


Two Problems:

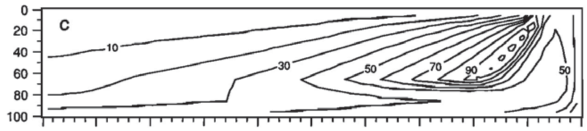
1. ^3H source originates at surface, not water table (^3H decays in VZ).
2. ^3H-^3He age has error from mixing processes.

Direct Simulation of Mean Groundwater Age (Goode, WRR, 1996)

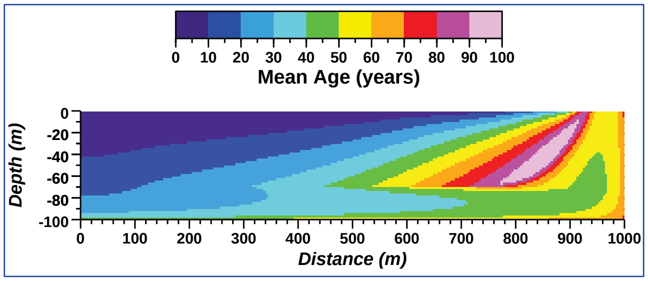
- Flow Velocity
- Stream Lines
- Mean Age
  - Diffusivity=0
  - Dispersivity=0
- Mean Age
  - Diffusivity = $1.16e^{-8} m^2/s$
  - D_L=6m, D_T=0.6m



Bethke and Johnson (2008) recommend using reactive transport modeling to interpret groundwater age isotope data.

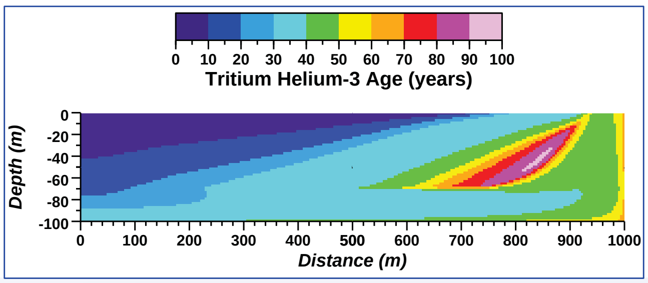


Direct Mean Groundwater Age (Goode, 1996)



From LLNL's NUFT code:

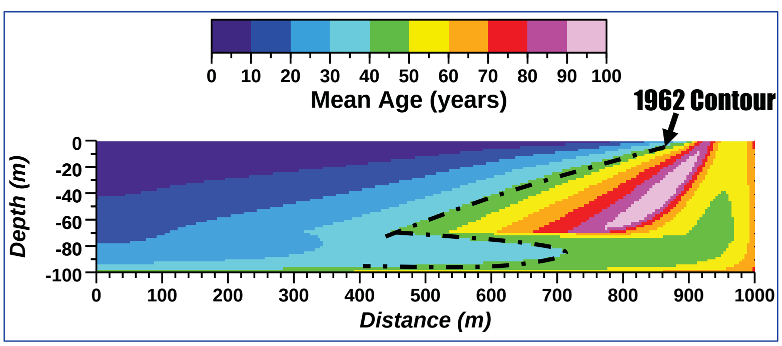
Mean groundwater age simulation assuming zero-order kinetic reaction of water to a water tracer component.



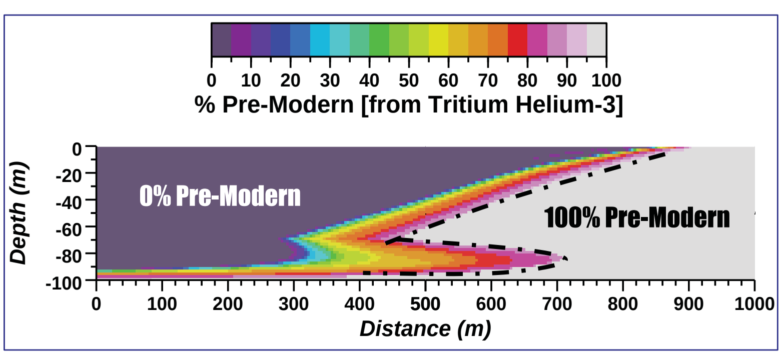
^3H-^3He age simulation considering:

- ^3H decay to ^3He = first-order kinetic reaction
- ^3H bomb curve
- ^3H and ^3He diffusion coefficients

"Pre-Modern" groundwater corresponds to pre-bomb peak groundwater.



Mean groundwater age at year 2002

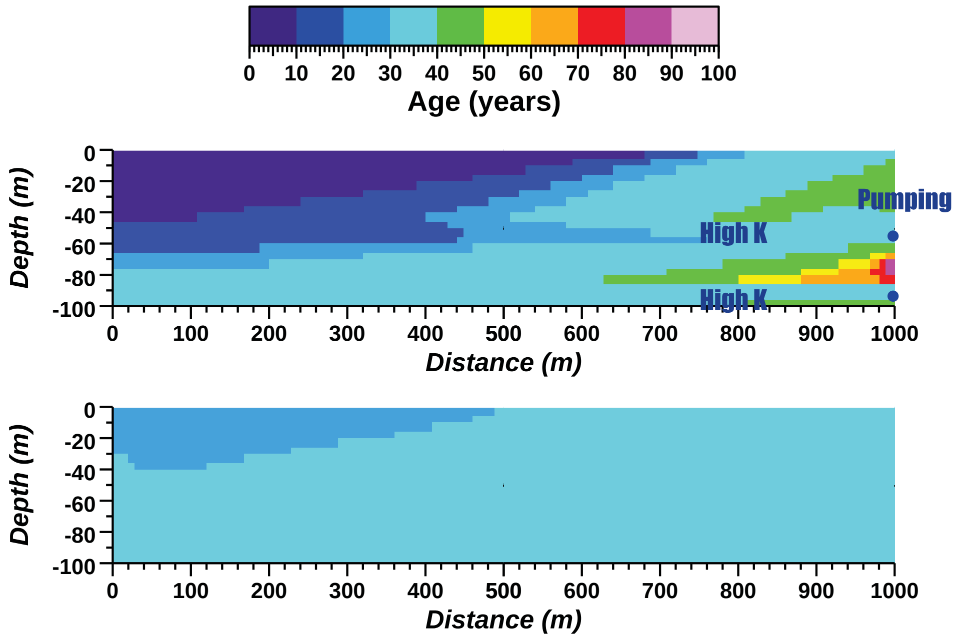


^3H-^3He "pre-modern" fraction at year 2002

Effect of dispersion on ^3H-^3He age.

No Dispersion:

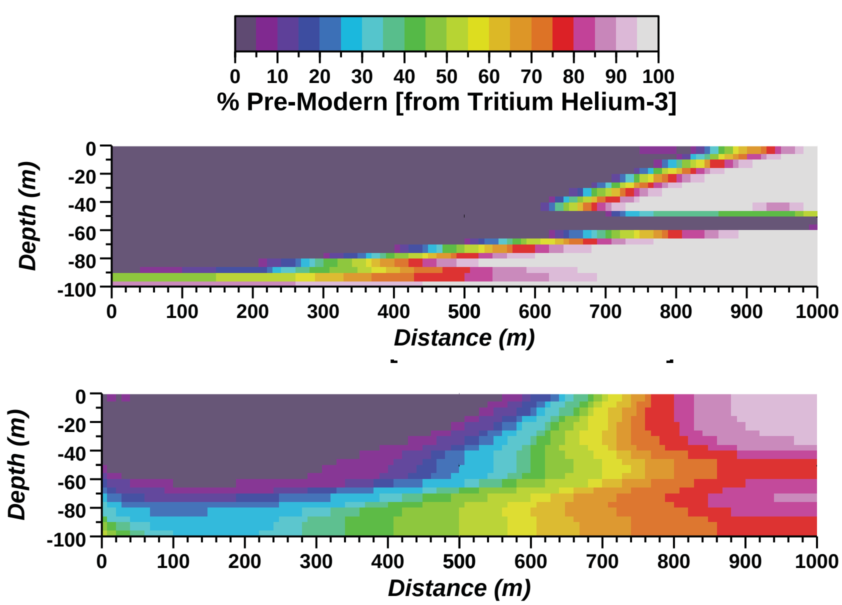
D_L=50m, D_T=5m:



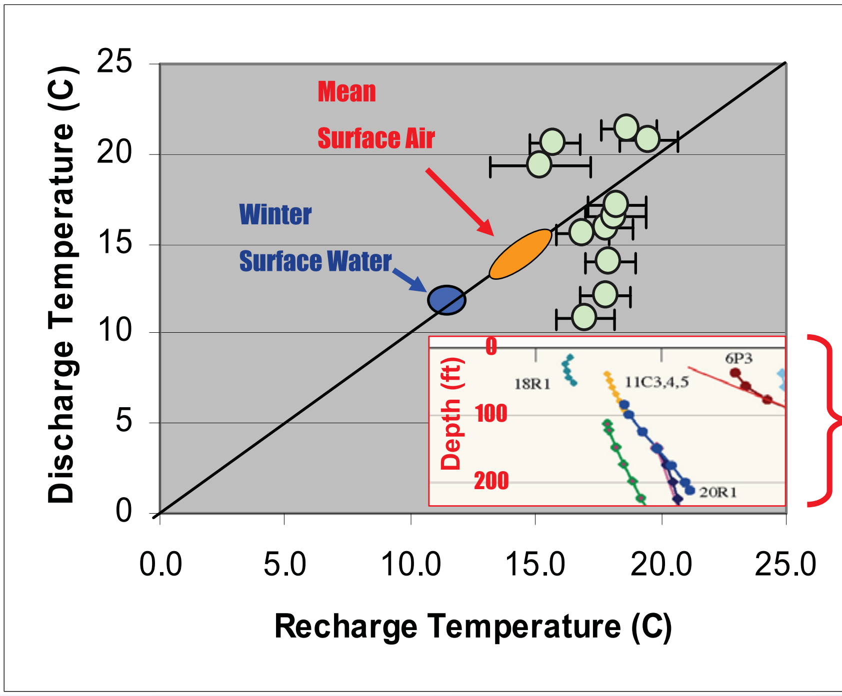
Effect of dispersion on %“Pre-Modern”

No Dispersion:

D_L=50m, D_T=5m:



Recharge temperatures correspond to vadose zone temperatures, not surface water or air temperatures.



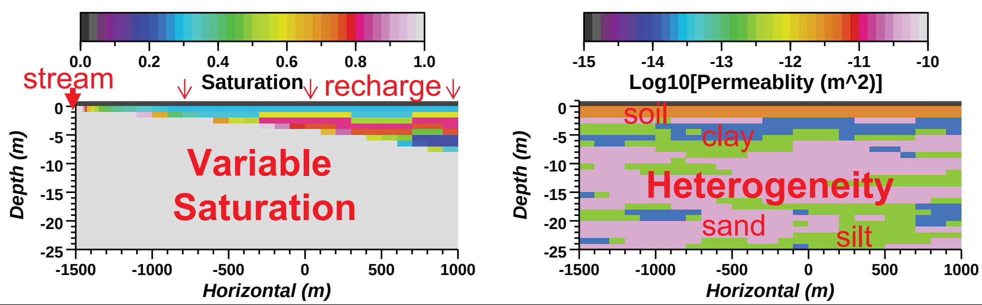
- Recharge passes through vadose zone
- ***^{3}He gas-liquid phase exchange***
- ***Zeros out age***

Temperature Logs From USGS (2006)

Simulation of ^{3}H-^{3}He Gas and Liquid Phase Flow and Transport Processes – A 2D Example

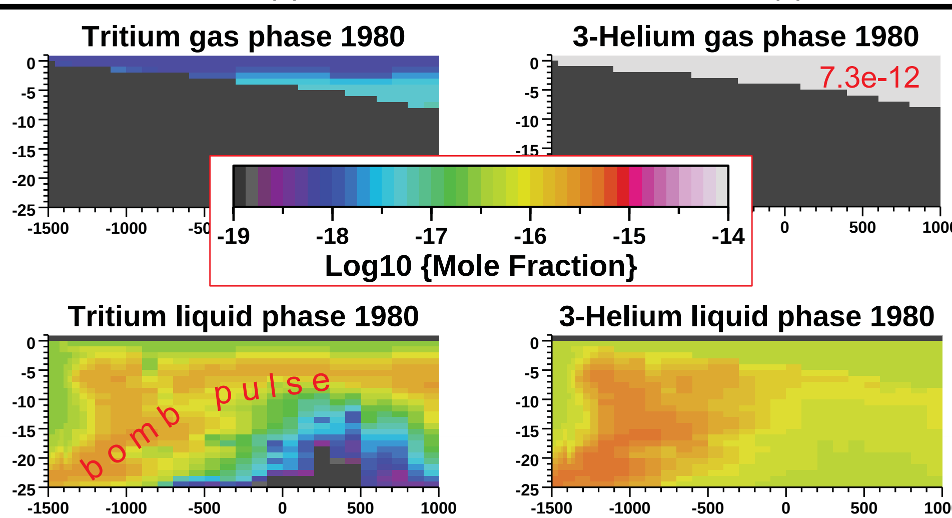
Flow

- Steady State
- Stream at Left Boundary
- 10 cm/yr recharge

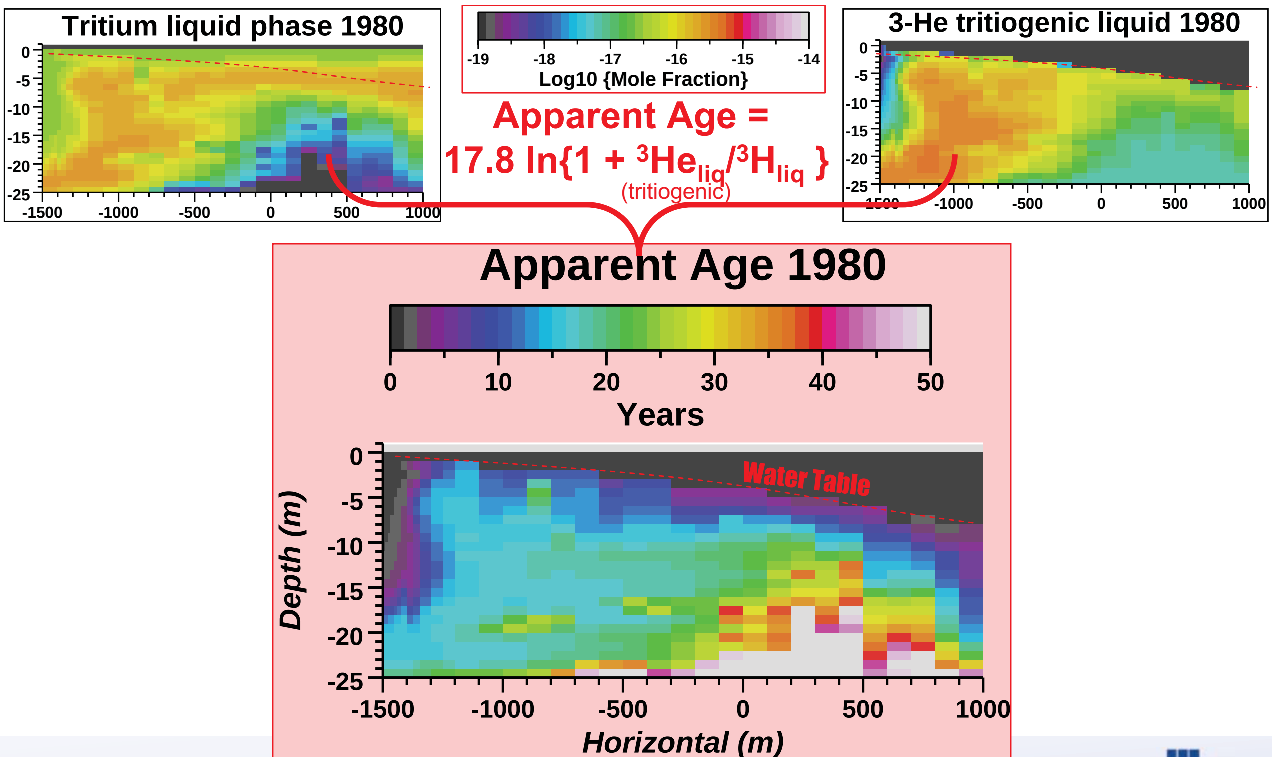


Transport

- Gas & Liquid Phases
- Water, Air, ^{3}H, & ^{3}He Components and Properties (e.g. ^{3}He diffusivity)
- ^{3}H and ^{3}He concentration boundary condition at land surface



Simulation of ^{3}H-^{3}He Apparent Groundwater Age Including Gas-Liquid Phase ^{3}H and ^{3}He Transport.



Conclusions and future work

- Dispersion can cause apparently old ^{3}H-^{3}He ages and high % pre-modern groundwater in shallow wells.
- Groundwater models should calibrate to ^{3}H-^{3}He age data using ^{3}H-^{3}He properties.
- Recharge temperatures, ^{3}H-^{3}He age, and % “pre-modern” suggest recharge spends time in vadose zone.
- We need to construct a 2-D groundwater flow model on the axis of Carriger Creek fan through El Verano to Sonoma Creek.